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Assessing Beyond Design Basis Seismic Events and Implications on Seismic Risk

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Assessing Beyond Design Basis Seismic Events and Implications on Seismic Risk

- Department of Energy Approach to Natural Phenomena Hazards Analysis and Design (Seismic)
- Design Basis and Beyond Design Basis Seismic Events
- Seismic Risk Implications – Key Parameters and Insights
- Conclusions

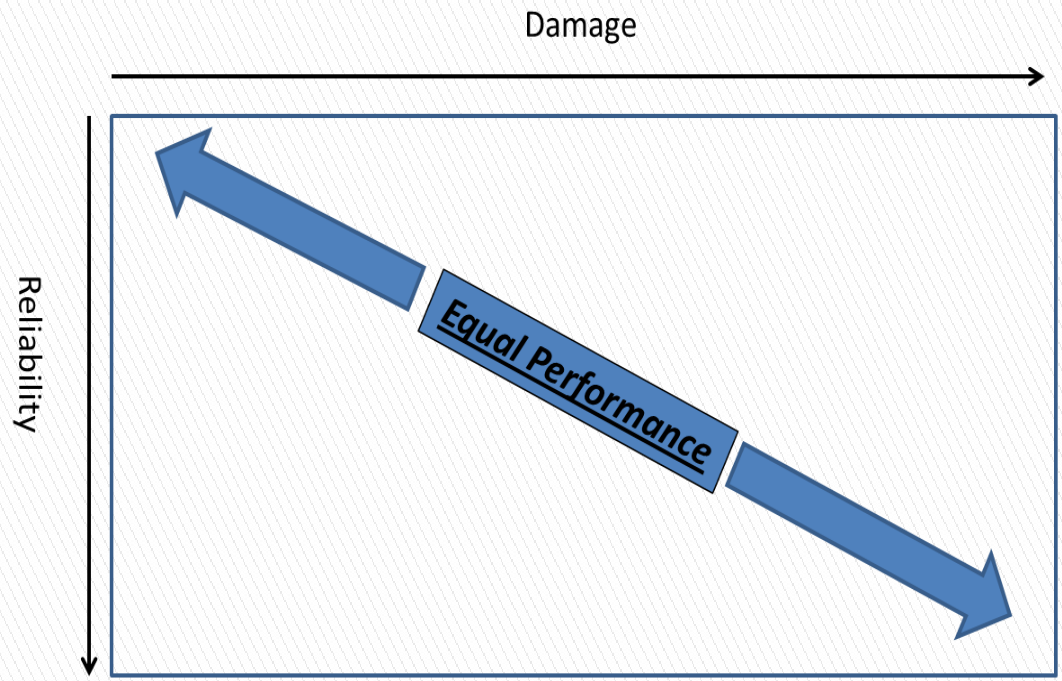
DOE Approach to Seismic Design is Performance Based

Damage is Assessed Using Limit States (LS)

- **Elastic – no permanent deformation. {LS-D}**
- **Fully Operational – limited permanent deformation but can perform function. {LS-C}**
- **Functional – moderate permanent deformation, emergency response. {LS-B}**
- **Life Safe – moderate to large permanent deformation, egress. {LS-A}**

Reliability is Assessed Using Performance Goals

- **Expressed as mean annual frequency of unacceptable performance**



First published as UCRL-15910, *Design and Evaluation Guidelines for DOE Facilities Subject to Natural Phenomena Hazards*, June 1990.
Later published as DOE Standard 1020, *Natural Phenomena Hazards Design and Evaluation Criteria for DOE Facilities*, April 1994.
Most recently published as American Society of Civil Engineers Standard ASCE/SEI 43-05, *Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities, 2005.*

DOE Approach to Seismic Design is Performance Based

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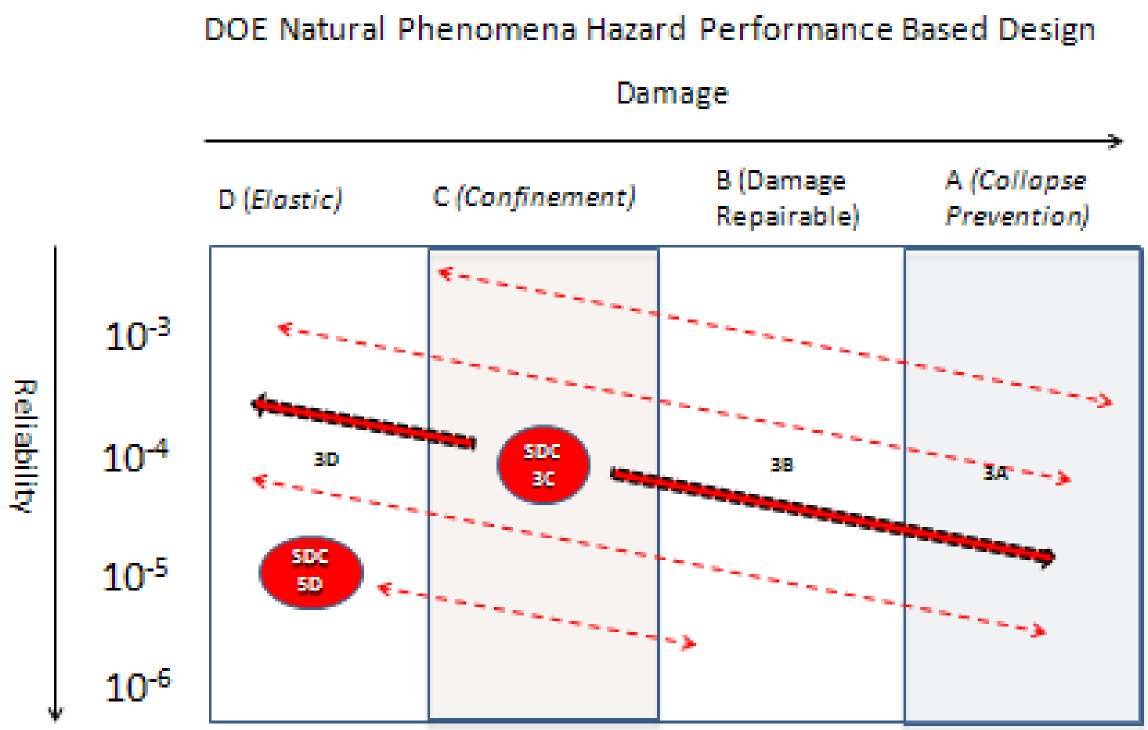
Seismic Design

5 Seismic Design Categories (SDC) are Combined with 4 Limit States (LS)

Each SDC/LS Combination Results in a Different Reliability Quantified Via a Performance Goal



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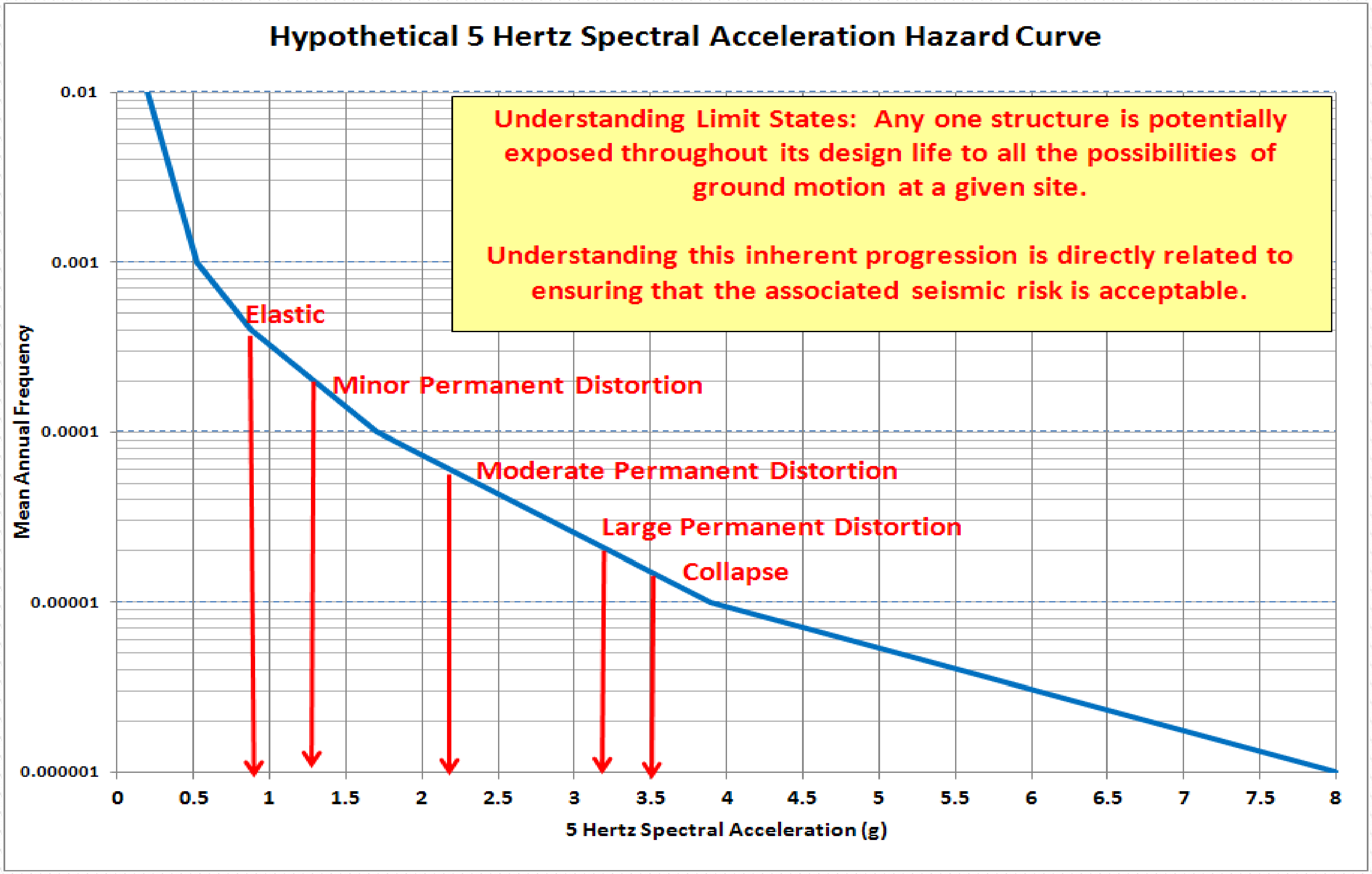
To estimate SSC seismic non-performance (failure to meet safety function or limit state), all ground motion intensities must be considered. Figure assumes 5 Hertz spectral acceleration best represents structural damage.



Performance Based Seismic Design for Nuclear Facilities (ASCE/SEI 43-05)

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Seismic Design Parameters				
Seismic Design Category	**Mean Hazard Frequency of Exceedance (HD)**	**Mean Annual Frequency of Unacceptable Performance (PF)**	**Ratio between HD and PF**	**Comments**
SDC3	$4x10^{-4}$	$\sim 1x10^{-4}$	4	The mean annual frequency of unacceptable performance is achieved by following the seismic design procedures contained in the standard. Important factors include; accounting for the slope of the hazard curve, acceptable seismic analysis approaches, load factors, material strength, proper seismic detailing {see ASCE/SEI 43-05 for a complete list}.
SDC4	$4x10^{-4}$	$\sim 4x10^{-5}$	10	
SDC5	$1x10^{-4}$	$\sim 1x10^{-5}$	10	

Unacceptable performance means failure to meet safety function as expressed using a Limit State. For example, if a structure is designated as SDC3 Limit State C, the mean annual frequency for lack of confinement from seismic is $1x10^{-4}$.

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Design Basis Events
Design Basis Seismic Events

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- What is a design basis event (DBE)? A postulated event used in the design to establish acceptable performance requirements of structures, systems, and components.
- DBE's can be described in several ways — for seismic, DBE is defined as a design response spectra per ASCE 43-05…however
  - All DOE sites are required to define the DBE seismic ground motion based on a probabilistic seismic hazard analysis (PSHA).
  - The PSHA can be used to assess which earthquake magnitudes and distances control the seismic hazard.
- DBE's are linked to accident analysis — the accident analysis is used to establish which SSCs are safety related (DOE = safety class). For each safety related SSC, safety functions and functional requirements are defined. For seismic these should be linked to SDCs and Limit States.
- The accident scenario assumptions also impact what can be considered a DBE versus a BDBE. For example, was facility total collapse used to derive unmitigated seismic accident consequences?
- If DBE or BDBE seismic scenarios are developed they should be consistent with the seismic hazard defined for the site.

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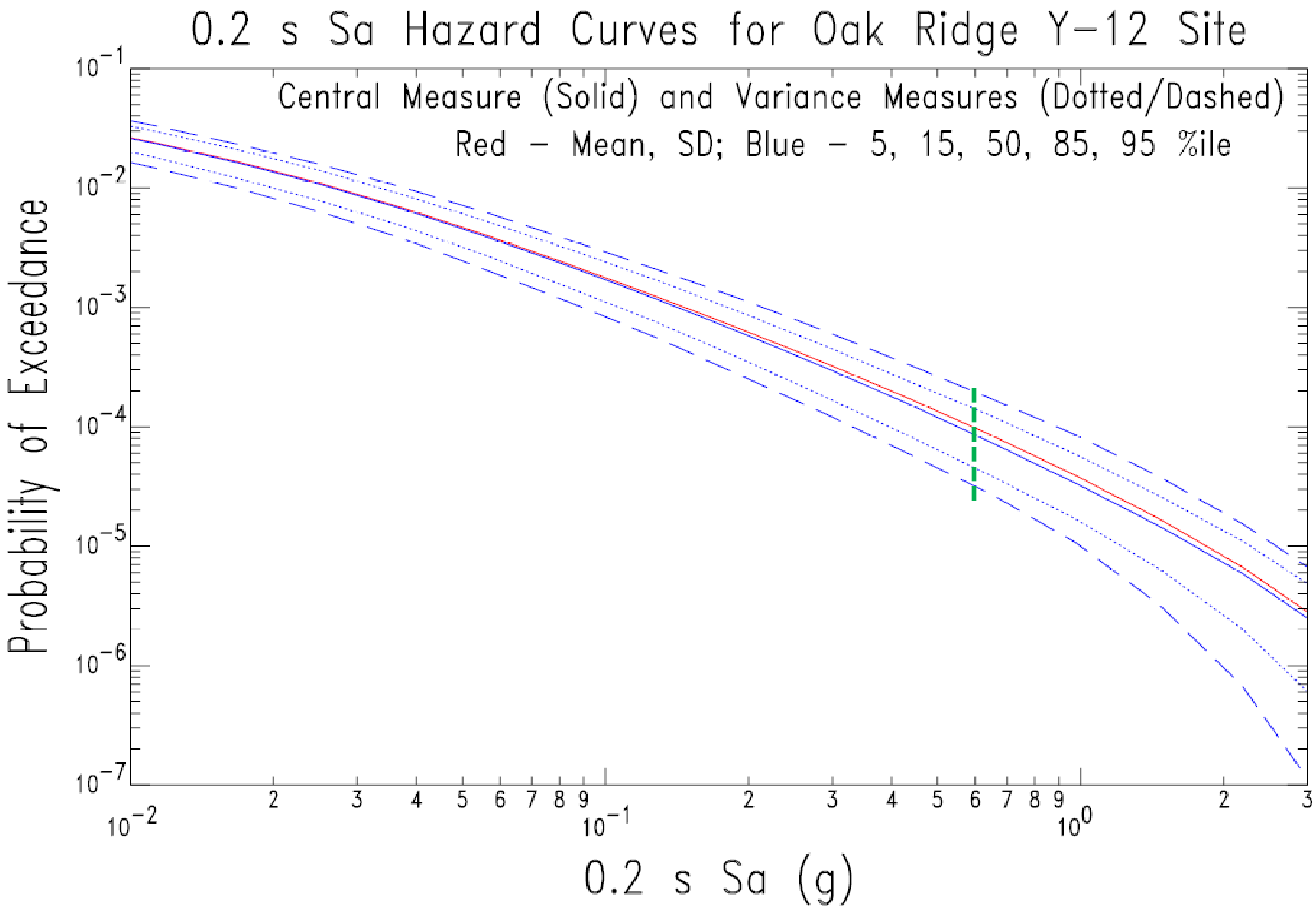
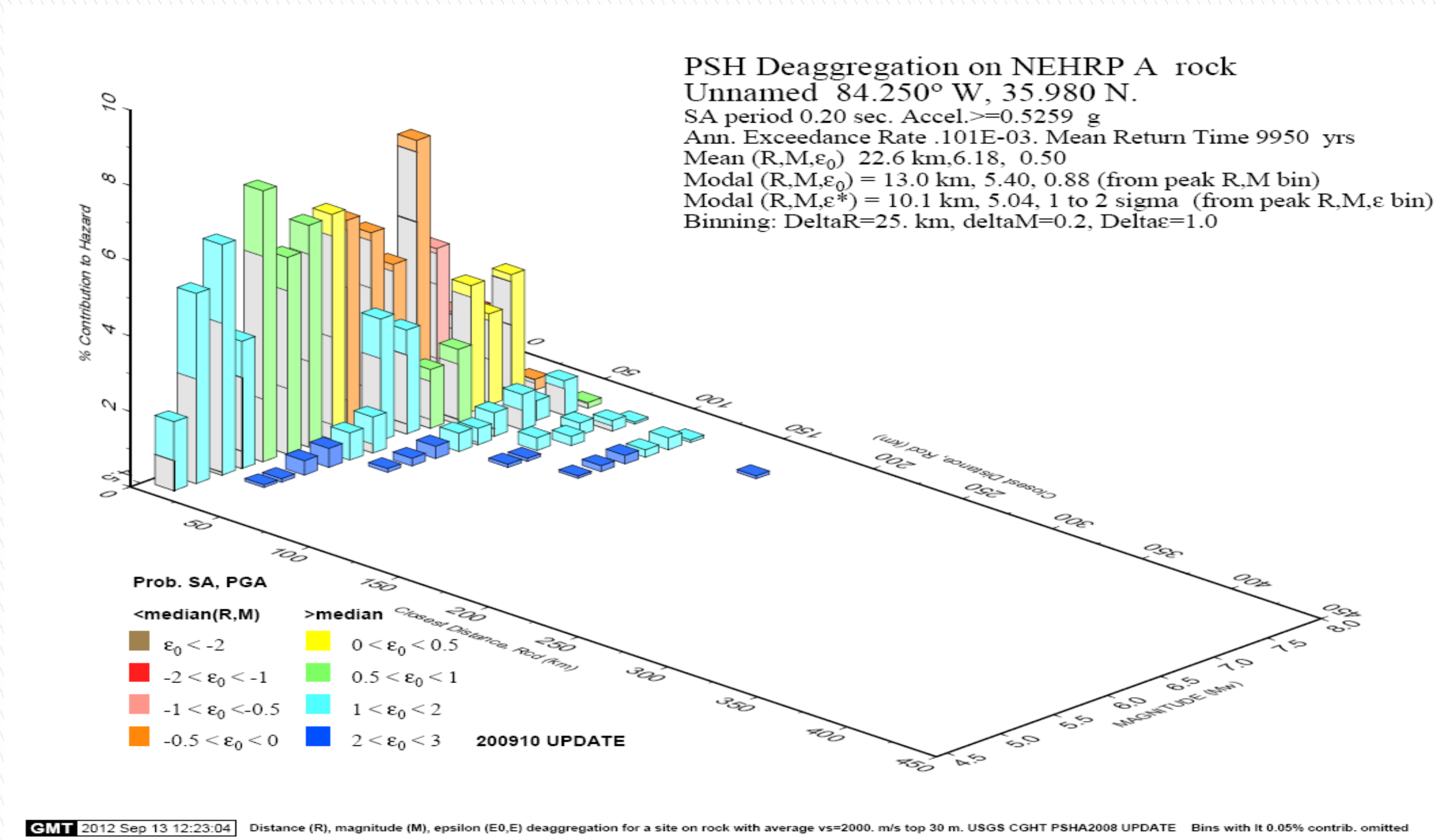
Example Probabilistic Seismic Hazard Analysis Curves for Y12 site



DBE Seismic Scenarios should be based on information consistent with the PSHA — what earthquakes control the seismic hazard?

Controlling magnitudes and distances at Y12, for 5 Hertz spectral acceleration at a return period of 9950 years; stiff nuclear structures are sensitive to structural frequencies near 5 Hertz



PSHA data can be used to establish scenario earthquakes for both design basis and beyond design basis conditions — examples for DOE sites with SDC3 structures where DBE is linked to 2,500 to 10,000 year return periods and beyond design basis is linked to 25,000 to 100,0000 year return periods

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Scenario Earthquake Magnitudes and Distances				
	Design Basis		Beyond Design Basis	
Site	Magnitude	Distance (km)	Magnitude	Distance (km)
SRS	5.7	36	6	19
Y12	5.9	24	6.2	17
Pantex	5.6	36	5.8	22
LANL	6.4	4	6.5	3
SNL	6.5	10	6.7	6
NV	6	10	6.1	8
INL	6.2	14	6.2	10
Hanford	6	15	6.1	11
LLNL	6.5	7	6.6	6

The magnitudes and distances should be combined with the anticipated ground motions from the DOE site PSHAs to fully appreciate anticipated damage if these scenarios occur. For example, emergency response exercises should be based on a realistic assessment of anticipated damage under larger ground motions associated with beyond design basis conditions.

Important Parameters to Consider as Part of Understanding Seismic Risk

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Risk = Frequency (x) Consequence

Consequences depends on source term (MAR (x) DR (x) LPF (x) **ARF** (x) **RF**

Relative Risk Insight – Examples for Bulk Pu Powder

Vibration ARF (x) RF = .0001 (V/V=1)

Spill ARF (x) RF = .0006 (S/V=6)

Impact ARF (x) RF = .002 (I/V=20)

Adding in DR and LPF may add to these relative differences

(V/V=1, S/V= 6+, I/V = 20++)

Seismic collapse may control seismic risk (as compared to non-collapse seismic accidents) unless frequency of collapse offsets the relative increase in consequences. Given seismic design is there an accident cliff for seismic collapse?

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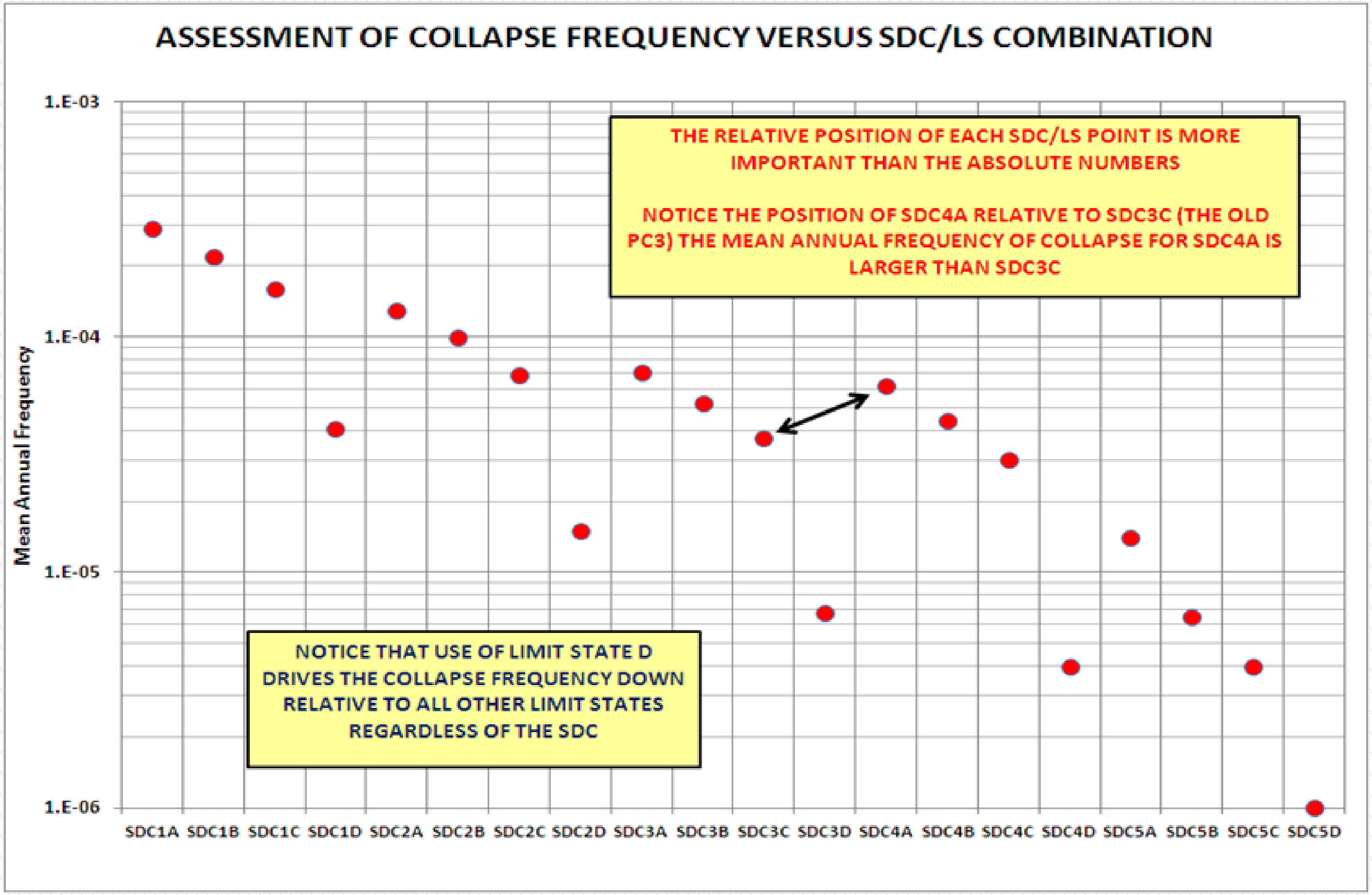
Important Parameters to Consider as Part of Understanding Seismic Risk – Seismic Collapse Frequencies



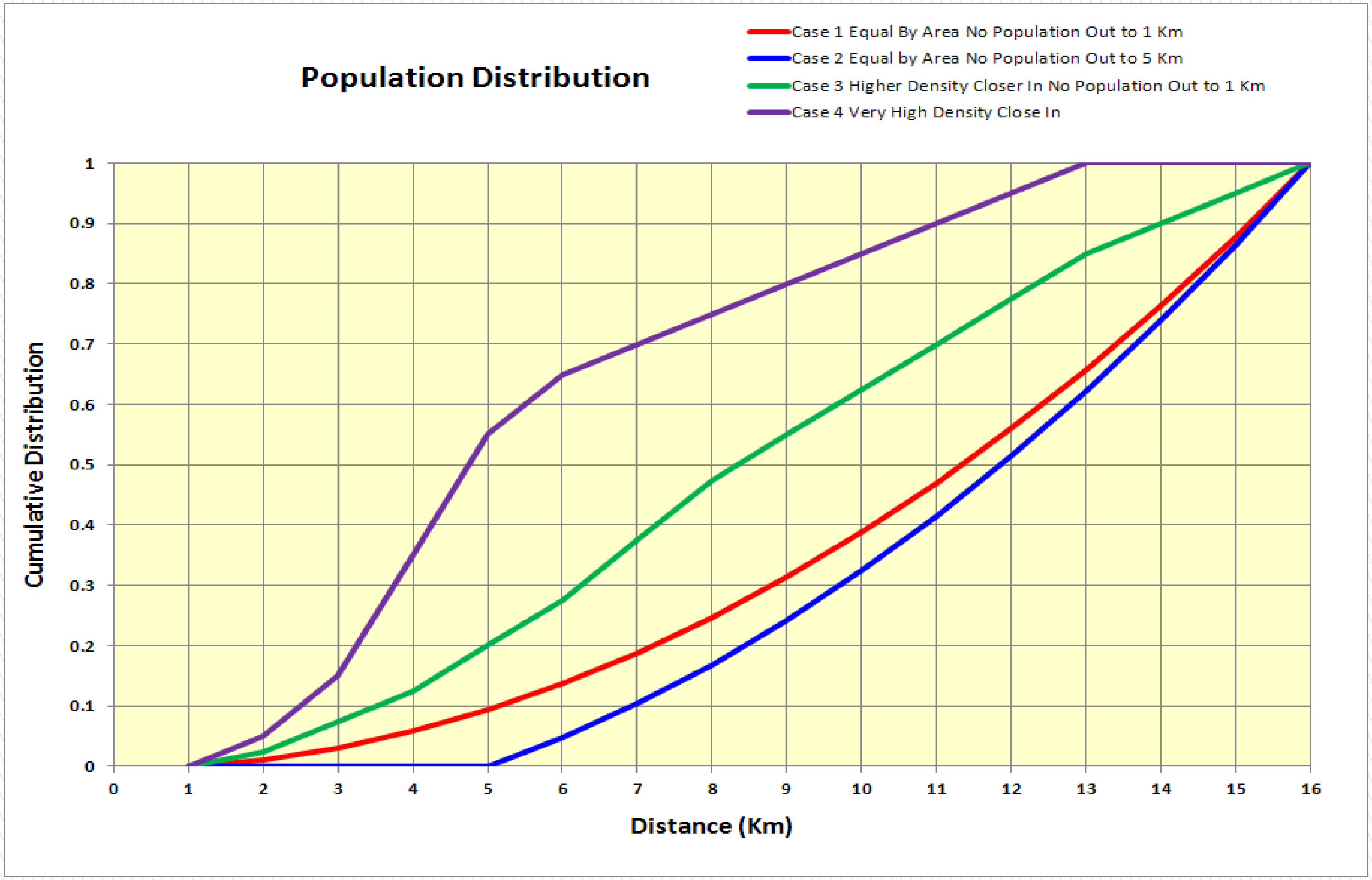
For SDC 3C the collapse frequency is only about a factor of 2 to 3 below the performance goal suggesting that seismic collapse may control seismic risk unless Limit State D is used for design

Seismic Risk Implications —How Infrequent do Seismic Accidents Have to be to protect public health and safety?

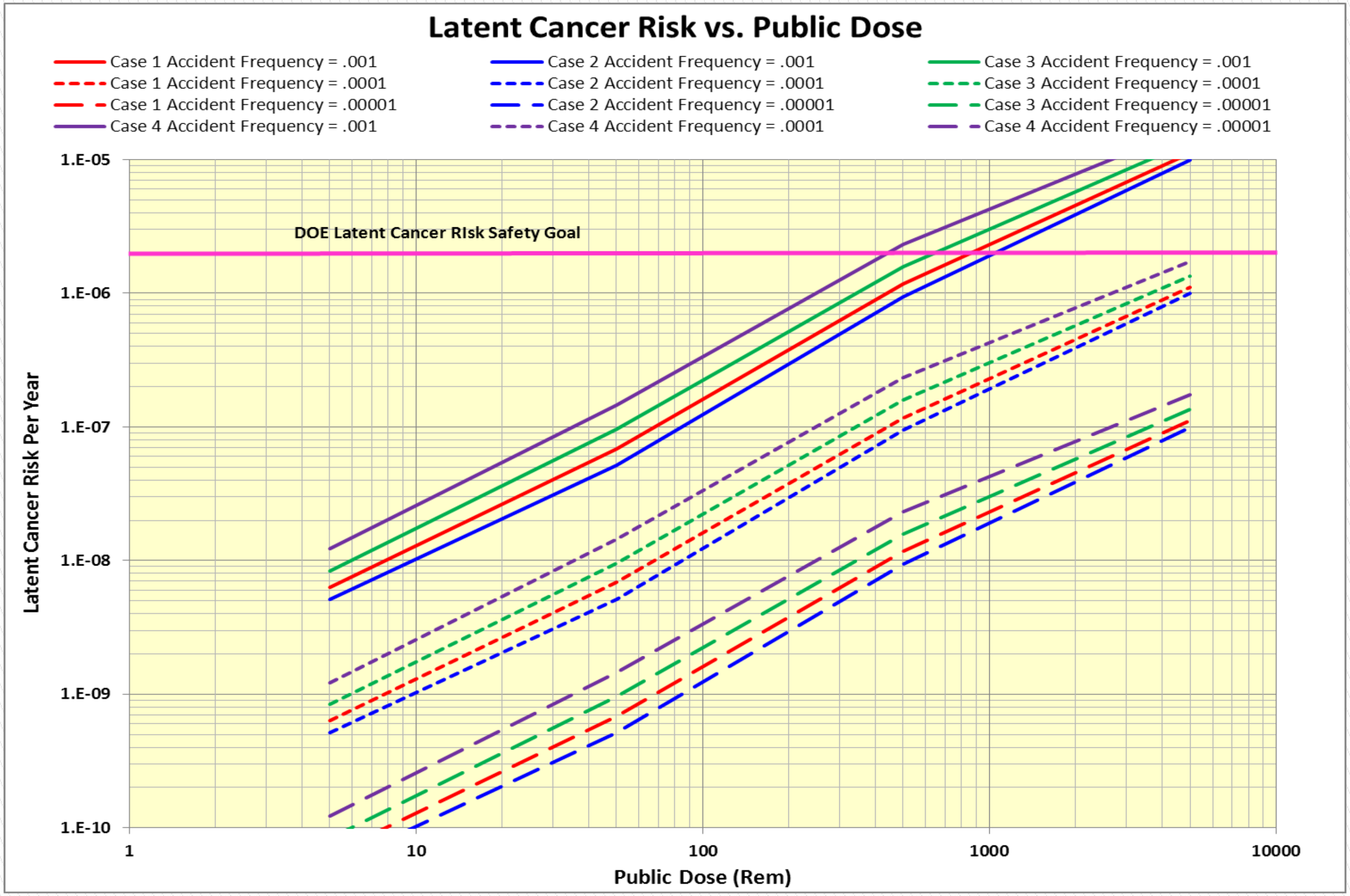
Simple assessment using Hotspot atmospheric dispersion code to estimate population exposure

- Wind directions equal weight
- Stability classes equal weight
- 4 different relative population distribution assessed for population within 10 miles (shown on next slide)
- Accident frequency varied to get insights into offsite dose versus Latent Cancer Risk per year
  - 3 accident frequencies assessed, 10^{-3}, 10^{-4}, 10^{-5} (think of these as seismic collapse frequencies)
  - 4 doses assumed at 1 km (5, 50, 500, and 5000 rem)
  - Plot dose versus LCF Safety Goal (DOE P 420.1) (shown below)
  - Insights from safety goal comparison should inform adequacy of seismic design approach

Relative Population Distribution Used For Seismic Risk Insight



Seismic Risk Implications For 4 Population Distribution Cases at 3 Accident Frequencies (Seismic Collapse Frequencies)



Seismic Risk Implications For 4 Population Distribution Cases at 3 Accident Frequencies (Seismic Collapse Frequencies)

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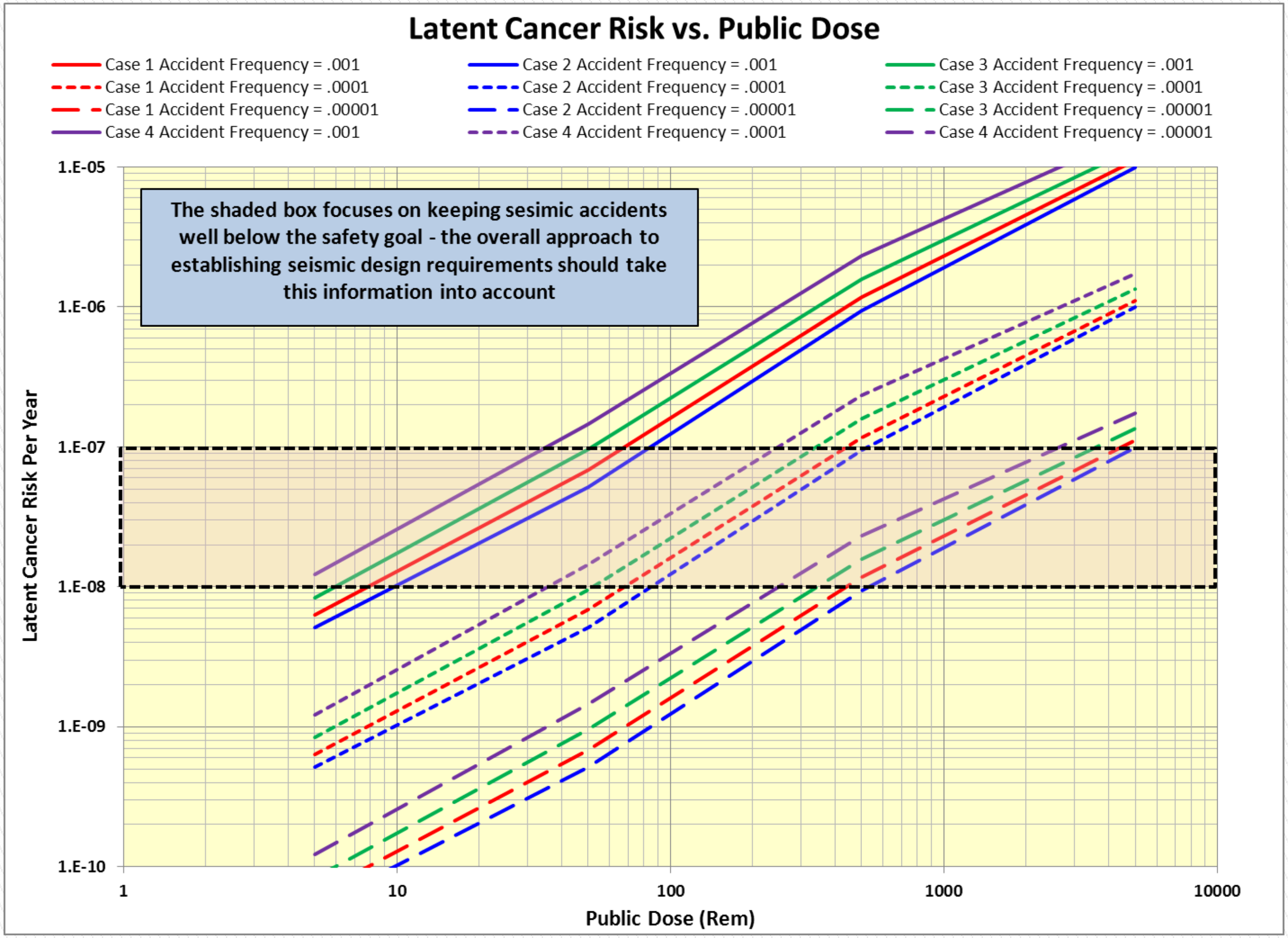
Approach to Seismic Design Should Result in Margins to Safety Goal – What Margins are Appropriate?



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Seismic Risk Observations

- **Accident frequency is important – seismic design must get to an acceptable accident frequency for seismic collapse**
- **Population density distribution is important especially when more people live closer to the facility**
- **Margin to safety goal is important – the seismic design requirements (SDCs and Limit State used for design) will dictate public (nuclear) risk to severe seismic accidents**
- **Regardless of whether you call seismic collapse a DBE or a BDBE, seismic collapse consequences should be evaluated.**

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Conclusions

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- **The entire probabilistic seismic hazard curve is important, don't just focus on design earthquake ground motion**
- **DBE and BDBE seismic scenarios should be consistent with seismic hazard defined for the site – BDBE should consider event annual frequencies up to 10 times lower than DBE event annual frequencies**
- **All structures will collapse at some ground motion, public (nuclear) seismic risk may be dominated by seismic collapse, population density is important – collapse cliff should be avoided**
- **Seismic accident collapse frequency needs additional definition to ensure DOE approach to seismic design is adequate – seismic collapse check may be needed for all new and existing Hazard Category 2 nuclear facilities.**

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